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LIGO: STATUS AND PROSPECTS

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ABSTRACT
The Laser Interferometer Gravitational-Wave Observatory (LIGO) is being developed to detect gravitational waves emitted from Astrophysical sources. The facility will consist of two widely separated laboratories housing highly sensitive long baseline interferometers using suspended test masses. The construction of LIGO began in 1995 with scheduled completion in 1999. The status and goals are discussed.

1. Introduction

Evidence that gravitational waves indeed exist in nature has been provided by the beautiful experiment of Hulse and Taylor, who measured the orbital period of a binary neutron star system, over a 15 year interval with great precision. They observed, with 1% accuracy, a decreased in the ~ 8 hour period of the orbit by about 10 seconds. This measurement is completely consistent with expectations from general relativity due to the emission of gravitational radiation.

The present situation experimentally is reminiscent of what occurred after the emission of neutrinos were proposed as the explanation for observations of apparent missing energy (and angular momentum) from some nuclear beta decay reactions. That lead to a concerted effort to 'directly observe' neutrinos through their interactions, which was finally accomplished 20 years later by Reines and Cowan. Since the time of the first direct observations, a rich field of neutrino physics has developed **both** to study the neutrino itself (this continues with the search for neutrino mass and oscillations), and the use of the neutrino as a sensitive probe of fundamental particle physics (quark structure of nucleon, neutral currents, etc.).

In analogy to neutrinos, for gravitational waves, following indirect observation, sensitive new instruments are now being developed for in the future, spherical detectors, to directly detect these waves. In this talk, I concentrate of the interferometer approach, and particularly those on the earth's surface (there are long range proposals *for such devices in space)* and *specifically for* the U.S. *Project* (LIGO). More detailed technical talks are presented elsewhere in this workshop.

2. LIGO

LIGO, the Laser Interferometer Gravitational-Wave Observatory,[1] is a joint MIT/Caltech project funded by the National Science Foundation. It will consist of two widely separated sites (3000 km), each having two 4 km arms in an L-shape and under high vacuum. These vacuum systems will house sensitive suspended mass interferometers which will be used for coincidence detection of gravitational waves. The experimental goal is to measure changes in distance of as little as 10^{-18}m in the separation of the masses in the arms over a frequency interval of 10-1000 Hz. The expected signal from a binary neutron star system, like the one observed by

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Gravitational Wave Detection

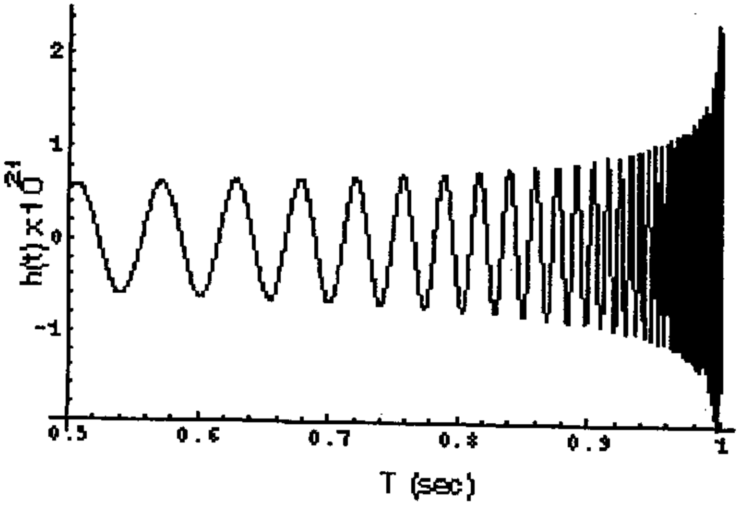

Figure 1: Binary neutron star coalescence 'chirp' signal.

Hulse and Taylor, is a so-called 'chirp' signal (Figure 1) that increases frequency and amplitude as it crosses our frequency bands during the last seconds of the inspiral and coalescence.

The 'benchmark' design goal of LIGO is to have sufficient sensitivity capability to observe such systems. The best estimates for rates, based on extrapolations of the statistics of neutrons stars in our galaxy yield ~ 200 Mpc (650 million light years) as the distance LIGO must be sensitive to, in order to observe three neutron inspirals/year. More optimistic estimates yield a distance of 23 Mpc, and *ultraconservative estimates yield 1000 Mpc.* With this guidance and experimental practicalities, the strategy for LIGO is to build an initial device that will approach the interesting region and be straightforwardly improvable to the best guess estimate. Furthermore, the overall LIGO facility design is such that future more sensitive interferometers can reach the conservative bound without being limited by the facility (e.g. the vacuum, the seismic isolation, etc.).

The LIGO configuration is shown in Figure 2 . A high power laser (initially 10W), which has been highly stabilized, is used as the light source. The laser is a Nd:YAG type with wavelength λ= 1064 nm. The laser beam is injected into the two arms of the interferometer by splitting the beam, and then the beam is servo-locked to the length of the interferometer arms. The detectors are set on a dark fringe and using the high photostatistics, small changes in distance are recorded by very finely 'splitting' the fringe.

The reflectivity's of the mirrors are selected and positions controlled to build up the beam in the resonant cavities and to optimize sensitivity. The parameters

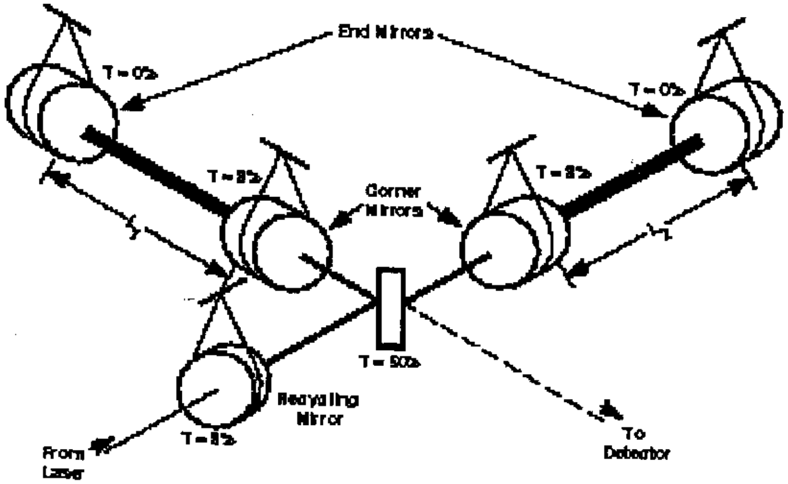

Figure 2: The optical system for LIGO.

OPTICAL CHARACTERISTICS	NOMINAL INITIAL INTERFEROMETER	SAMPLE ENHANCED INTERFEROMETER
Arm Length	4000m	4000m
Laser Type & Wavelength	Nd:YAG $\lambda = 1.064\mu m$	Nd:YAG $\lambda = 1.064\mu m$
Input Power,P	6W	100W
Contrast Defect, $1 - c$	3×10^{-4}	3×10^{-4}
Mirror Loss, L_M	1×10^{-4}	1.3×10^{-5}
Power Recycling Gain	30	380
Arm Cavity Storage Time, τ_{Arm}	8.8×10^{-4} s	1.3×10^{-3} s
Cavity Input Mirror Transmission, T	3×10^{-2}	2×10^{-2}
Total System Loss, $L_T = (T + A$ +Scattering)	4×10^{-2}	3×10^{-3}

Table 1: LIGO interferometer optical parameters.

Internal to the beam tube, baffles are inserted to reduce scattered light off the walls getting into the system. Vibrations of the walls cause modulation of this light which can create phase noise background. To reduce this problem, special baffles treated to be absorptive at laser wavelengths are installed. They are serrated at the edge to minimize diffractive effects.

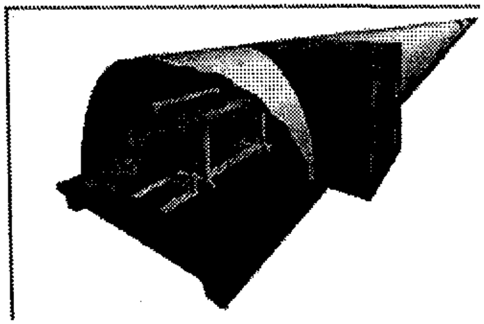

Figure 5: Beam tube and enclosure for LIGO.

The vacuum requirements are stringent in order to insure that gas scattering will never a factor to the noise floor, even in advanced detectors. The pressure required to meet this goal is that we obtain $< 10^{-9}$ torr for all residual species. That has been achieved in a 130 ft prototype beam pipe assembly that in all essential ways is identical to the actual LIGO beam tube. We believe the production tube is of higher quality due to rigorous quality control and about 3 km have been completed with no known leaks.

All the conventional facilities for LIGO are well underway and will be completed in 1999. The initial interferometer design is being finalized this year and some long lead items are already under construction. By the year 2000 we expect to be commissioning the initial interferometers, testing them and soon after we will do an initial search for gravitation waves. Our goal is to reach our initial design sensitivity indicated in Figure 3 by 2002 at which point we hope to detect gravitational waves.

In any case, the detector sensitivity will be improved systematically by incremental enhancements in the following years, allowing detection if the rates are low.

The indicated improvements expected in a 5-10 year program are also shown in Figure 3. If gravitational waves have already been observed, the improvements will afford the opportunity to increase the rates to where LIGO will be able to initiate a new field of research - gravitational wave astrophysics.

References

1. A. Abramovici *et. al.*, *Science* **256** (1992) 325.